WFIRST Status

October 29th, 2019

Jeffrey Kruk
WFIRST Project Scientist

• NASA GODDARD SPACE FLIGHT CENTER • JET PROPULSION LABORATORY •
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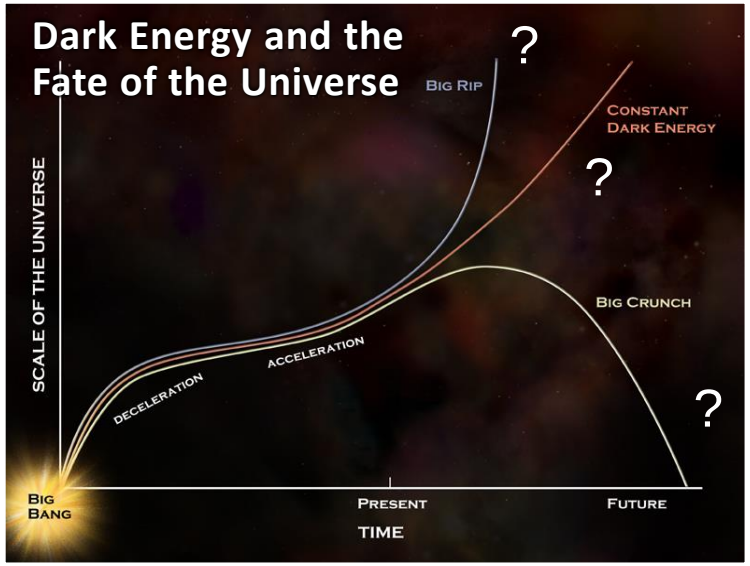
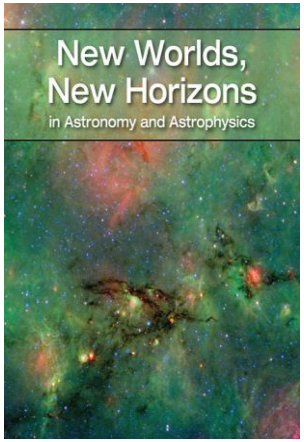
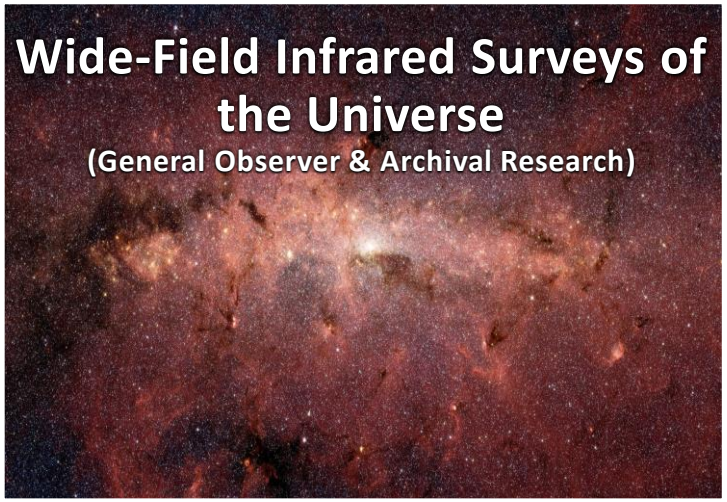
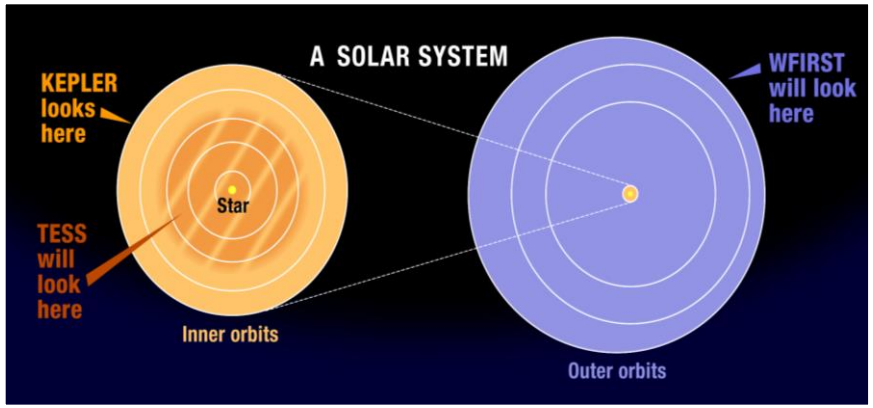
Science Program (no changes)







The full distribution of planets around stars



Overview

- Last presentation to the APAC was a year ago, shortly after the last of the System Requirements Reviews for the major mission elements.
- Only changes to the mission baseline since then:
  - Addition of low-dispersion slitless prism optimized for supernova spectroscopy
    - Replacement for descoped Integral field channel in wide-field instrument
  - Descope of coronagraph integral field spectrograph
    - Replaced by slit spectrometer

  (more about both of these changes later)

Technical Progress

- WFIRST has made substantial progress this year
- Preliminary Design Reviews drawing to a close:
  - Instrument Carrier: Complete (May 29th)
  - Wide Field Instrument: Complete (June 18th)
  - Telescope: Complete (August 22nd)
  - CGI: Complete (September 17th)
  - Ground System part 1 (MOC): Complete
  - Mission/Spacecraft: Oct 28-Nov 1
  - ~130 internal reviews in 2019 in preparation for element PDRs
  - Most review team requests for action have been closed
    - Expect to close remainder in near future

Technical Progress

- Spacecraft
  - Working with Launch Services Program on an updated Coupled Loads Analysis from SpaceX
    - Additional launch vehicles to be run over the next year
  - Design complete for PDR; most subsystems ready for prototyping
  - Procurement activities:
    - Awarded or in process: high-gain antenna (HGA) gimbal actuators, TWTA and S-band transponder, propulsion latch valves, reaction wheels (RW)
    - Later in 2019: RW isolator, gyros, solar array substrate, Outer Barrel Assembly structure, Ka-band antenna, HGA boom damper, spacecraft primary structure

Technical Progress

- Telescope
  - Work is progressing on plan
  - Primary mirror figuring is on track; full tool polishing complete, now in ion figuring run #4
    - Total of 6 ion figuring runs planned
  - Disassembly of all inherited hardware is complete
  - Re-figuring of secondary mirror has begun
  - Thermal zones & control approaches defined (nearly all optical and baffle surfaces ≤ 265K)
  - Engineering models of new & modified components being built

Technical Progress

- Instrument Carrier
  - Interface details for instrument latches being negotiated
  - Thermal control algorithm trade closed last month
  - Structure procurement activities are on track
    - Contract awarded for composite components
    - Titanium forgings for nodes already procured
    - Launch lock & vibration isolation system contract awarded

Technical Progress

- Coronagraph Instrument
  - Grassroots exercise completed; re-scope efforts conducted in conjunction with science teams and project management.
  - HQ concurred with proposed plan to rescope Integral Field Spectrograph (IFS) to address cost, schedule, mass, & power issues
    - Formal change to Level-1 requirements at KDP-C
  - Spectroscopy to be done with slit & zero-deviation prism in same optical path as the direct imaging camera
    - Preliminary assessment for single planet spectroscopy is favorable
    - Lose ability to observe multiple planets simultaneously, to monitor changing speckle backgrounds, to demonstrate IFS wavefront sensing (not one of the critical technology demonstration objectives)
  - Mask design optimization continues (throughput improvement from pupil design; fabrication processes have been finalized)

Technical Progress

- Wide-Field Instrument
  - Thermal control of filters improved
    - Minimize changes to wavefront when filters are changed
  - Prism design finalized (optimized for SNIa spectroscopy)
    - SN teams have converged on straw-man observing plan
  - Numerous incremental mechanical & thermal design updates
  - ASIC: second-generation design complete & sent to foundry
  - Flight detector deliveries ongoing
    - Over a dozen delivered already
  - Grism assembly engineering unit undergoing tests & characterization
    - Diffraction efficiency close to model prediction

Technical Progress

- Ground System
  - MOC and ground station design is on track
    - Technical interchanges on ground stations w/ international partners continuing
      - Both JAXA and ESA to provide Ka-band antennas
    - Planning & scheduling system architecture work has begun
    - Data processing system architecture work beginning
    - Calibration plan close to being baselined
    - MOC PDR held, Science Operations PDR early next Summer

Programmatics

- Re-planned to FY19 budget (Feb 2019); operating in FY20 and planning future years based on optimal funding profile
  - Reserve posture remains healthy, exceeding requirement
- Maintained development schedule through FY19: absorbed furlough impacts and recovered
  - Delays were in detectors, instrument carrier and systems. These have been made up in revised schedule to KDP-C.
  - Major element engineering milestones being met
  - Reserve posture is still healthy, meeting requirement
- Have successfully ramped up the work force for our peak budget year, FY20

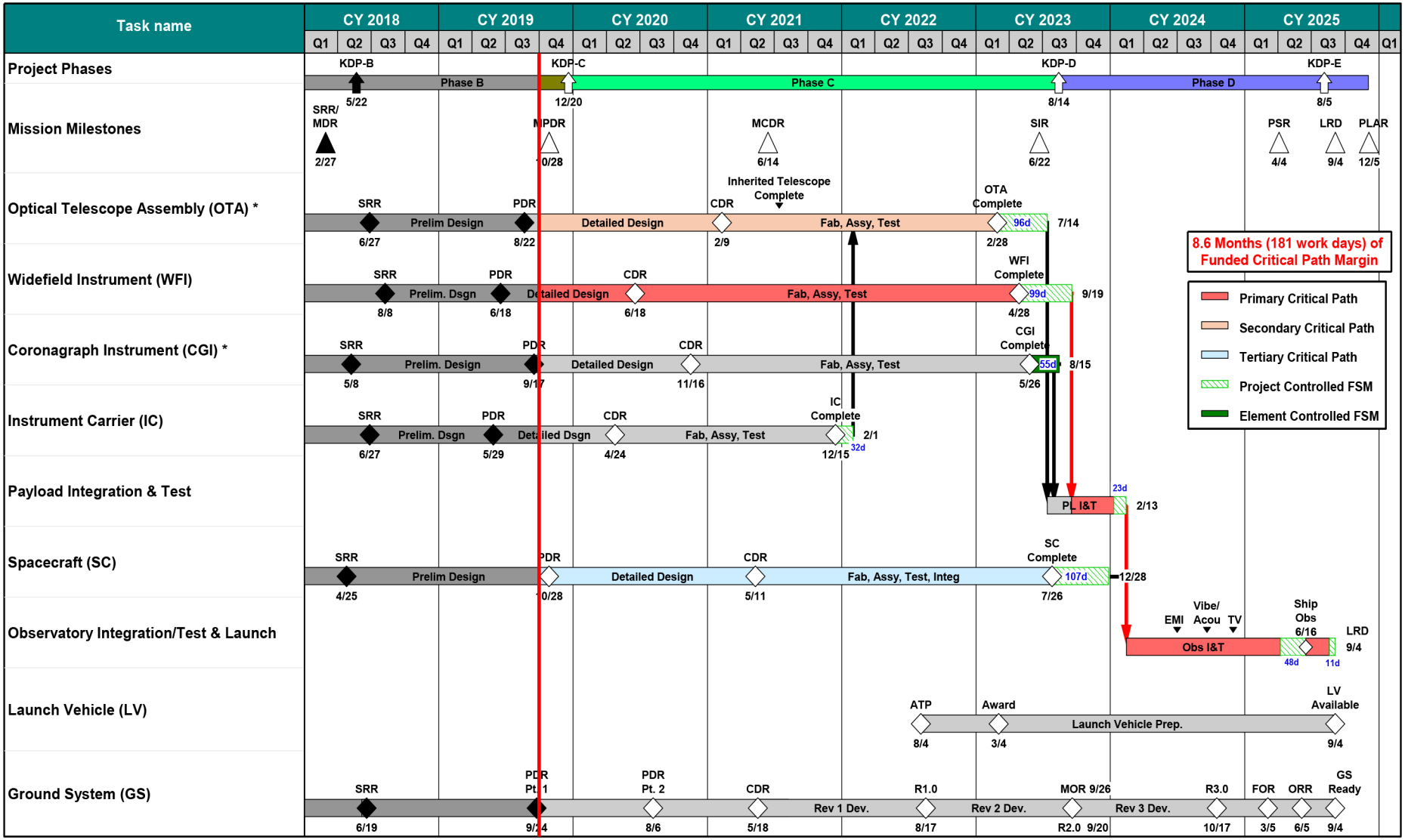
- Finalized contract with STScI, IPAC in process (expected by Dec 1)
- International partnership agreements drafted by agencies
  - Beginning formal approval process

Programmatics

- Confirmation Review (KDP-C) now expected early February
  - Depends on schedule for Agency Program Management Council
- Path to KDP-C
  - Complete Mission PDR
  - Complete Budget & Schedule JCL (Joint Confidence Level) assessment
    - Report drafted; not yet released
  - Other independent cost & schedule estimates:
    - Internal GSFC assessment (separate from Project)
    - Standing Review Board assessment
  - Goddard Center Management Council Review (Dec 2nd)
  - Science Mission Directorate Program Management Council (Dec 17th)
  - Agency Program Management Council (early Feb ?)

WFIRST Project Schedule as of 9-30-2019

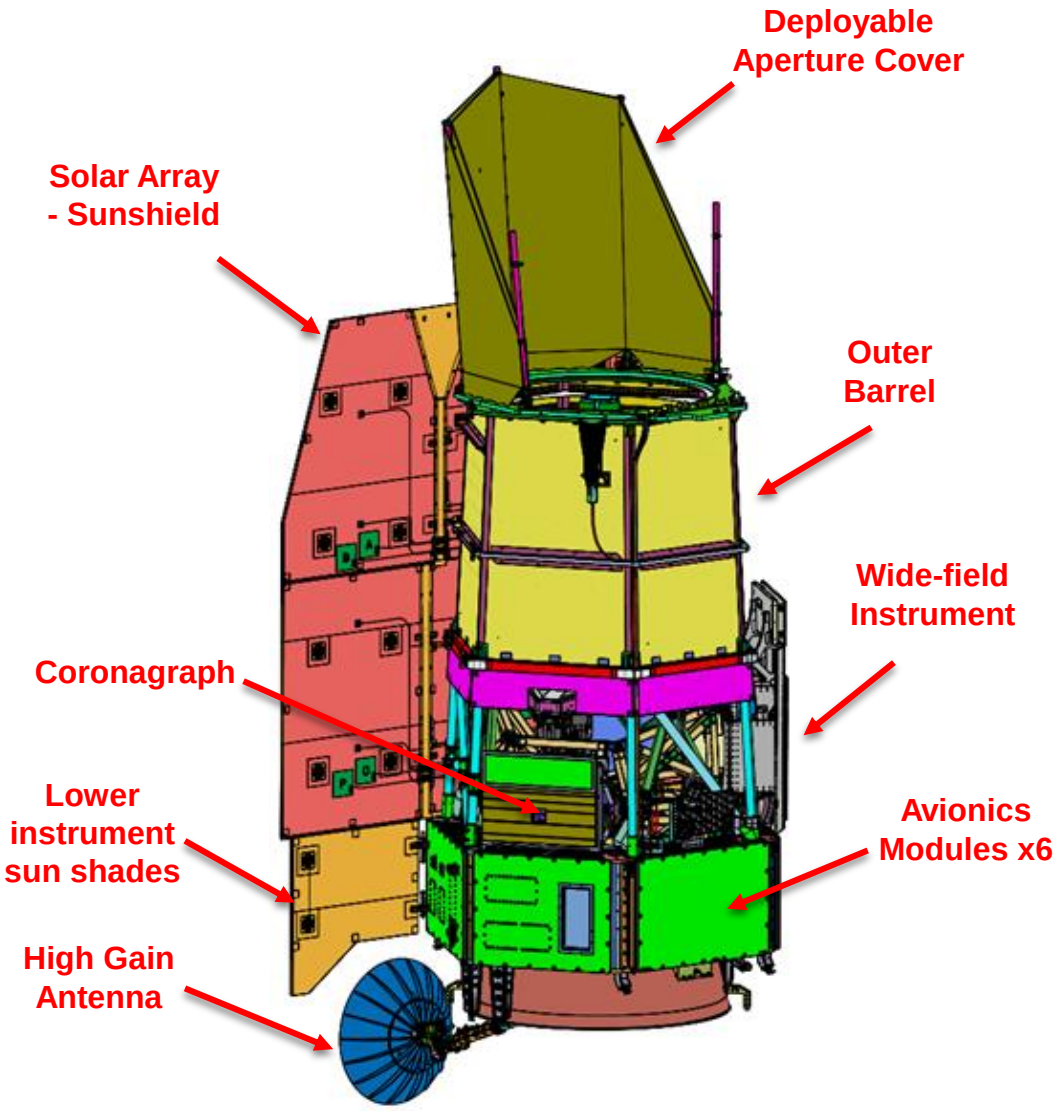
Preliminary WFIRST Development Schedule



*Secondary critical path is occupied by the Optical Telescope Assembly (OTA) in lieu of the Coronagraph Instrument (CGI), which is designated as a technology demonstration

*CGI schedule is draft pending review of direct imaging spectroscopy implementation

Observatory Concept



Key Features

Telescope: 2.4m aperture

Instruments:

- Wide Field Imager / Slitless Spectrometer
- Internal Coronagraph with Integral Field Spectrometer

Data Downlink: 275 Mbps

Data Volume: 11 Tb/day

Orbit: Sun-Earth L2

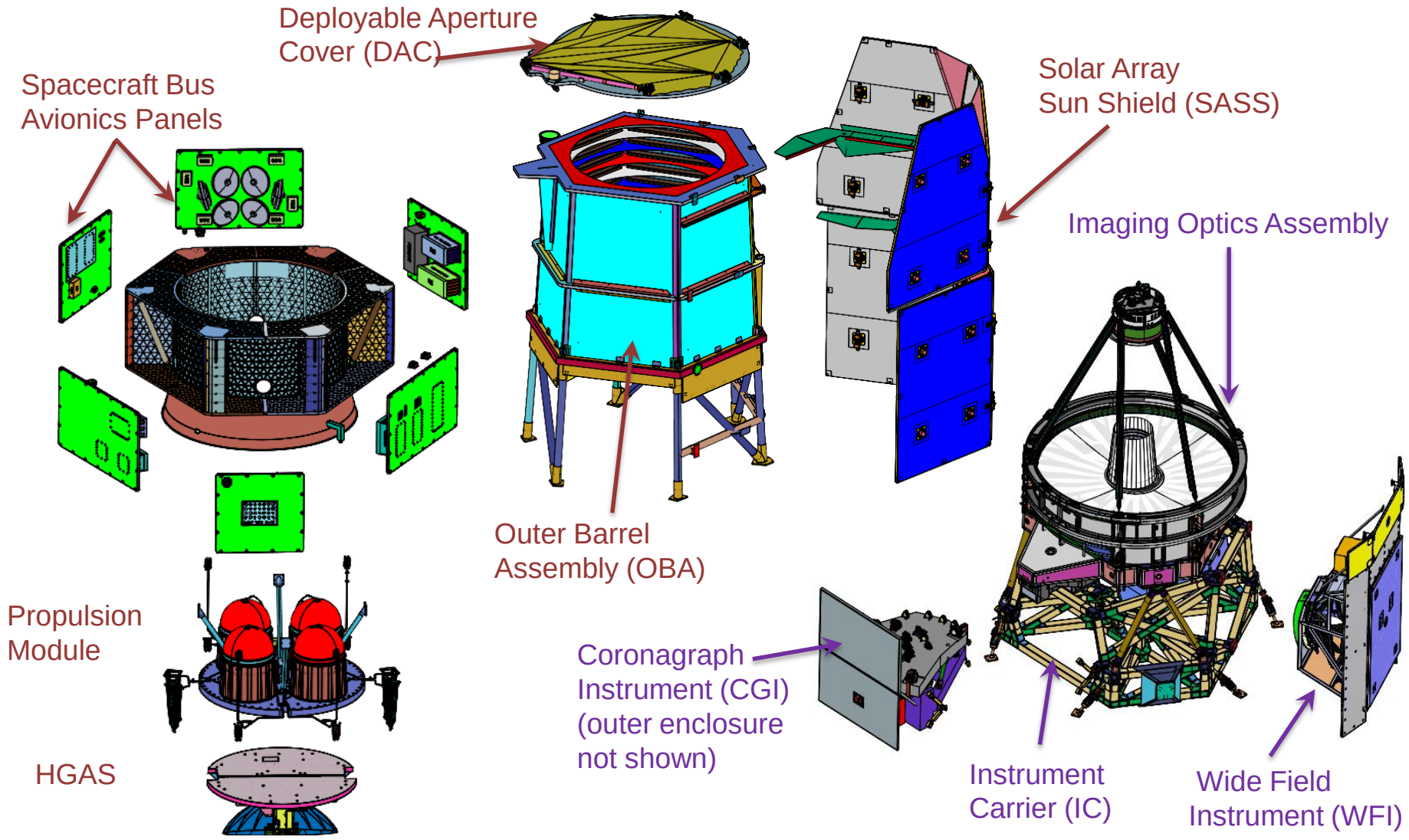
Launch Vehicle: 3 options

Mission Duration: 5 yr, 10yr goal

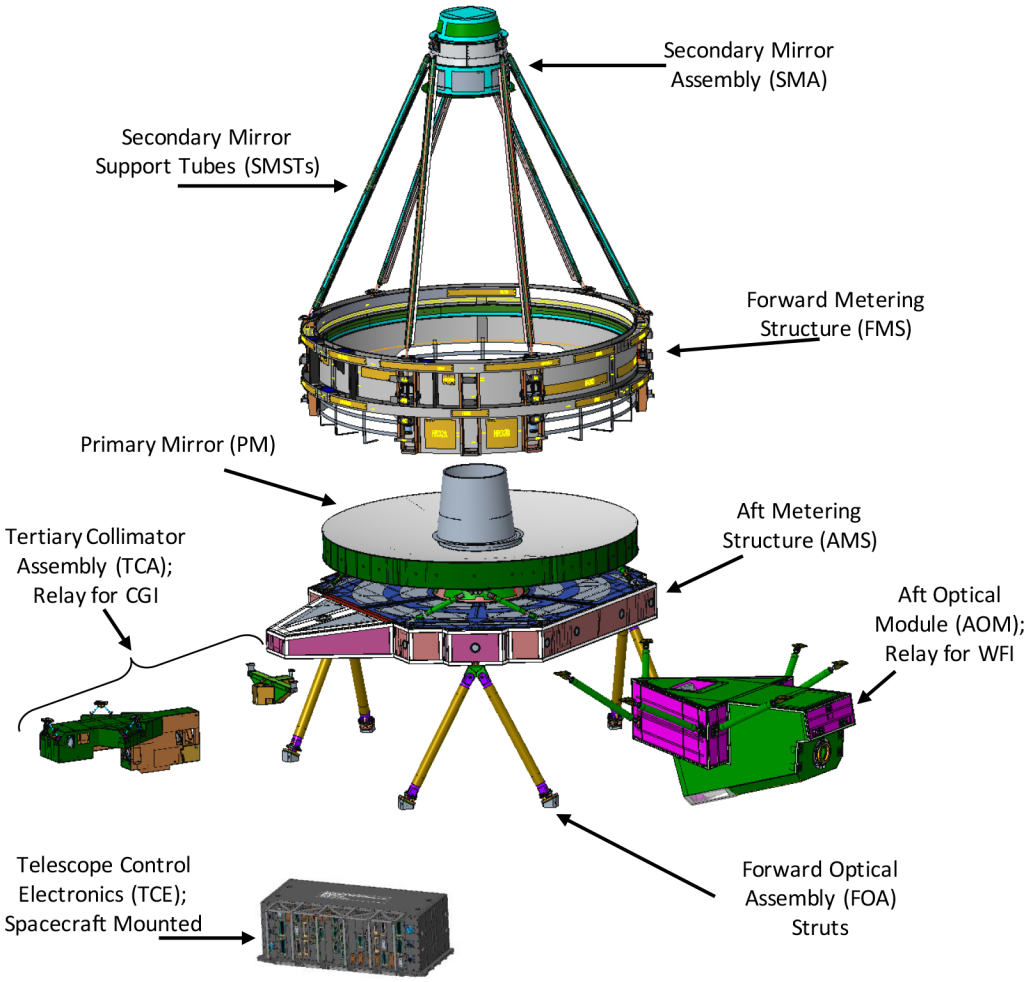
Serviceability: Observatory designed to be robotically serviceable

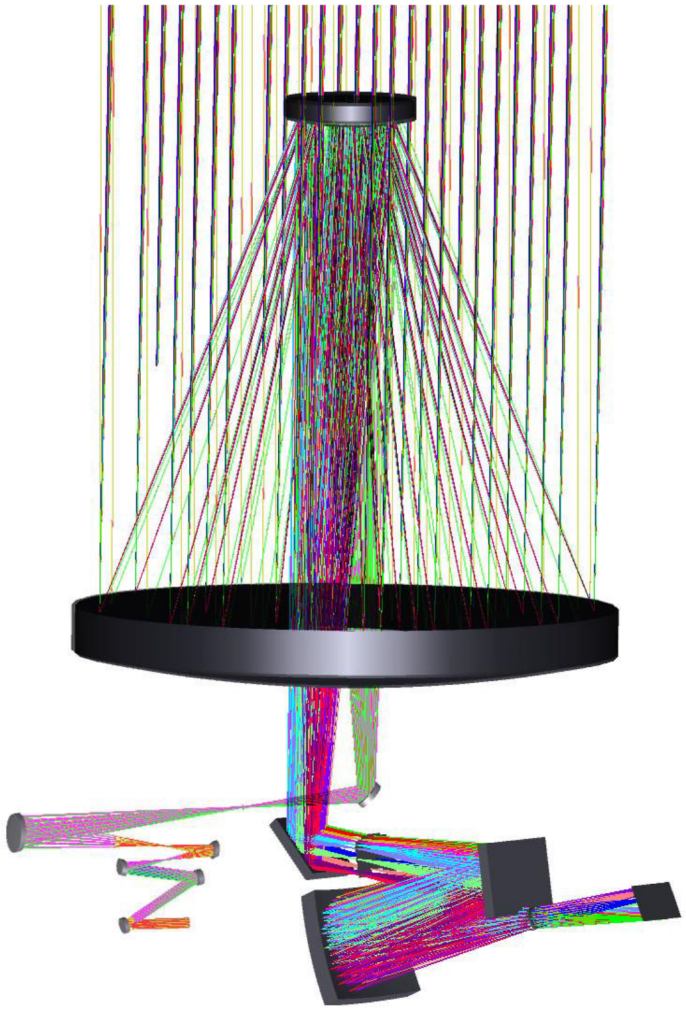
Starshade compatible

Observatory Expanded View



OTA high-level view

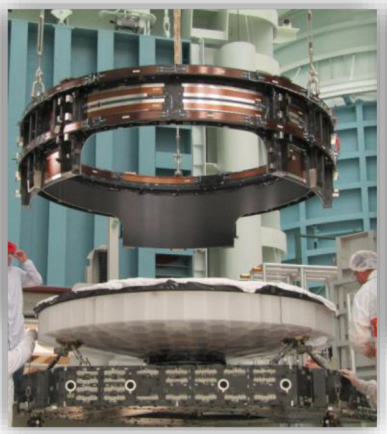




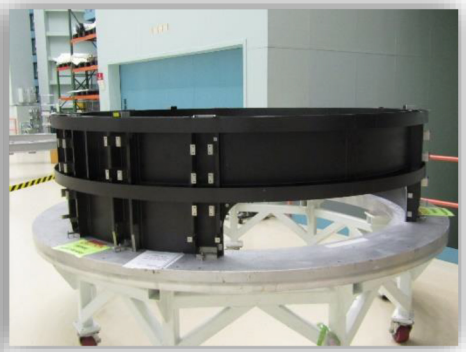
Inherited hardware progress (1)

Primary Mirror Assembly + Forward Metering Structure At SRR/Pedigree Review

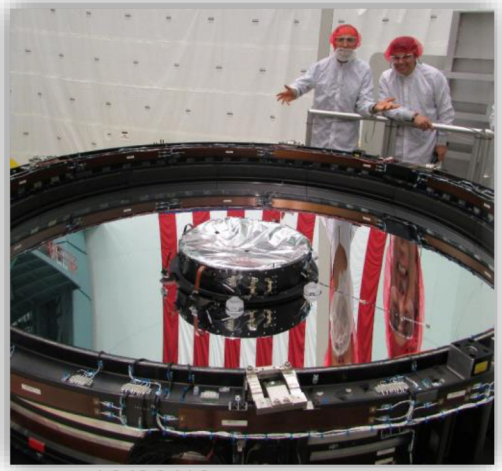
Removal of PM Scraper 7/2018



Forward Metering Shell Removal 7/2018

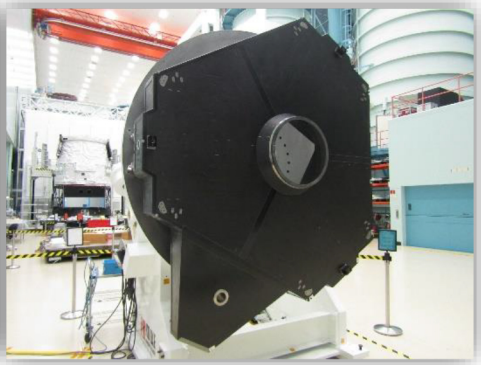


Forward Metering Structure June 2019



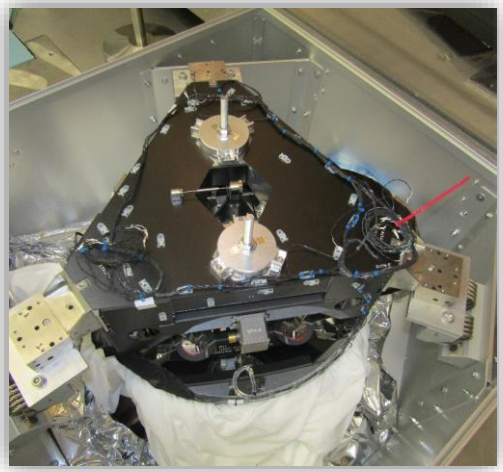
Removal of PM Baffle Adaptor 7/2018

Removal of Spare PM from Aft Metering Structure May 2019

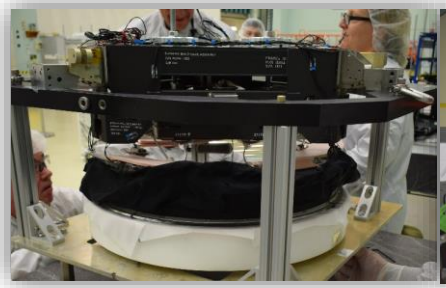


Aft Metering Structure June 2019

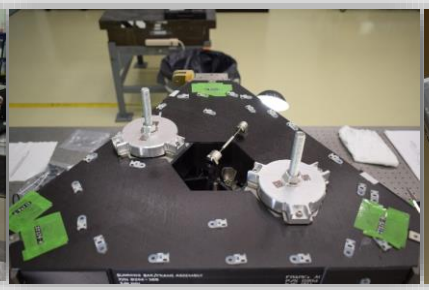
Inherited hardware progress (2)



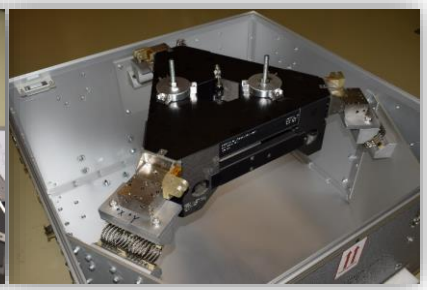
Secondary Mirror Assembly At SRR/Pedigree Review



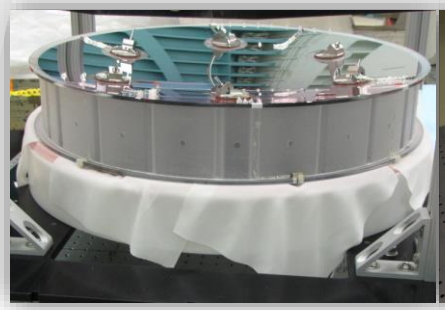
Disassembly of support structure from mirror



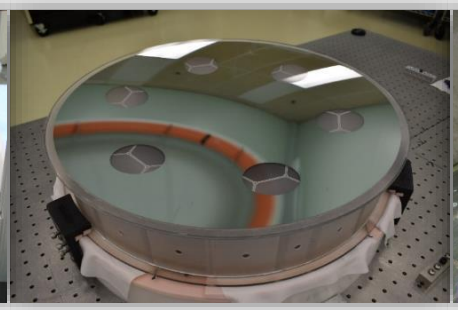
Removal of thermal-electric hardware



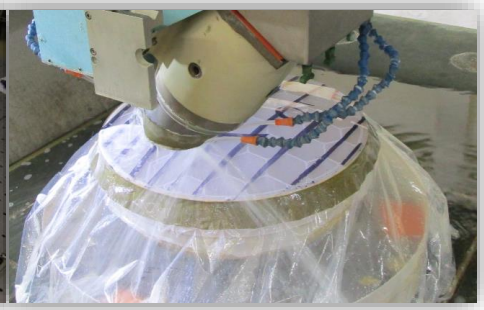
Secondary Mirror Support Structure (SMSS) ready for re-use



Secondary Mirror (SM) de-configured from support structure

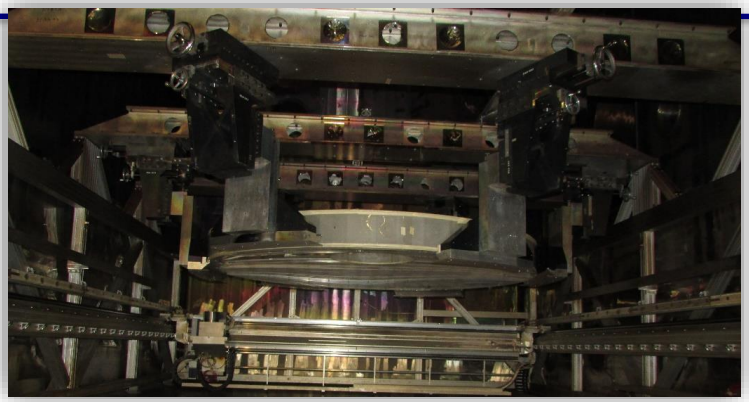


Back Pad Removal



In process shaping of SM to WFIRST prescription

Inherited hardware progress (3)



Ion Figuring - Ongoing

Flight Primary Mirror (SN#3) As received

Full Tool Polish May 2019

IC Architecture

Structure

- Provides stiff, strong, and stable support for WFIRST Payload
- Similar construction to JWST ISIM
  - Leveraging lessons learned
- Includes:
  - Composite tubes and gussets
  - Ti nodes and clips; Harness brackets
  - ST/IRU mount

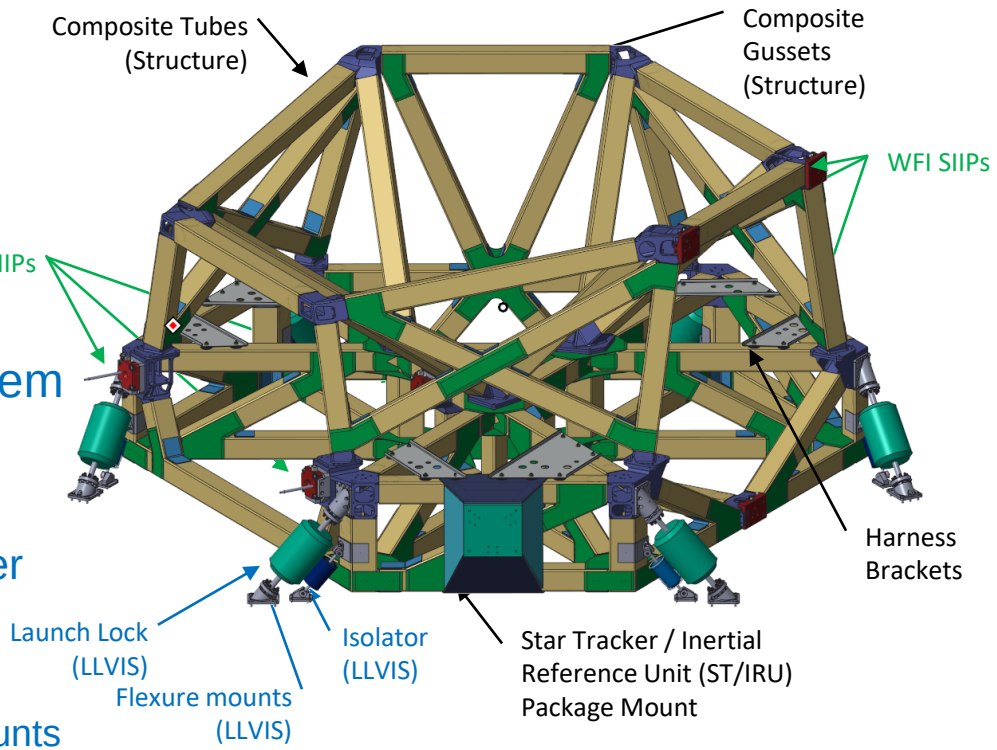
Launch Lock and Vibration Isolation System (LLVIS)

- Mounts Payload to SC for launch (locked)
- Isolates the WFIRST Payload from SC jitter (unlocked)
- Includes:
  - Launch lock; Vibration isolator; Flexure mounts to IC and SC

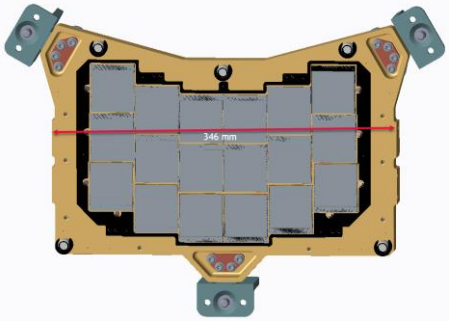
Science Instrument Interface Plates (SIIPs)

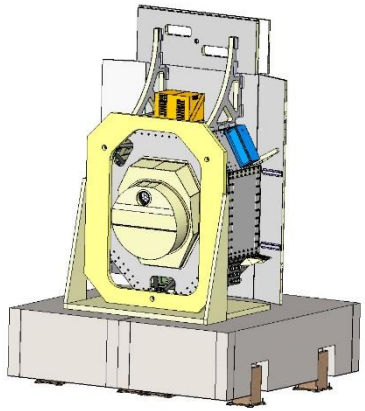
- Align instruments to telescope pupils
- Similar to ISIM SIIPs
  - Leveraging lessons learned

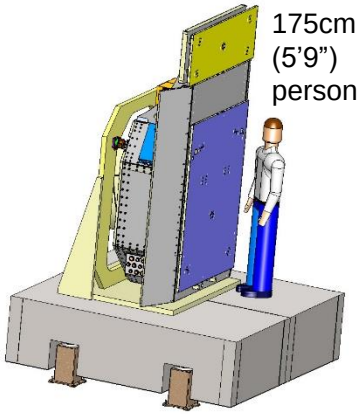
IC = Structure + LLVIS + SIIPs



WFI Cold Sensing Module







175cm (5'9") person

Focal Plane Electronics (FPE)

Sensor Cold Electronics Assembly (SCEA)

293K

150K

Mosaic Plate Assembly (MPA)
Larger detector area than an iPad display

Telescope Aft Optics Module

140K

220K

95K

Alignment Compensation Mechanism (ACM)

180K

RCS Projection Optics

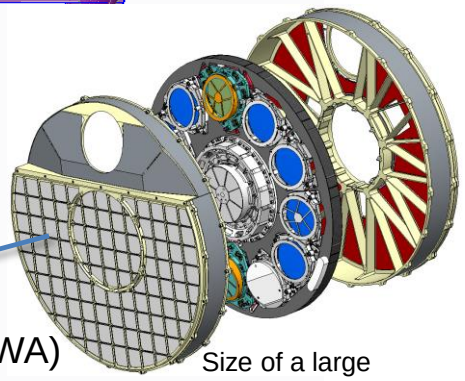
Relative Calibration System (RCS)

WFI NTE Envelope

140K

220K

Element Wheel Assembly (EWA)
7 sci filters, phase retrieval filter, grism, prism, dark (~∅100mm)

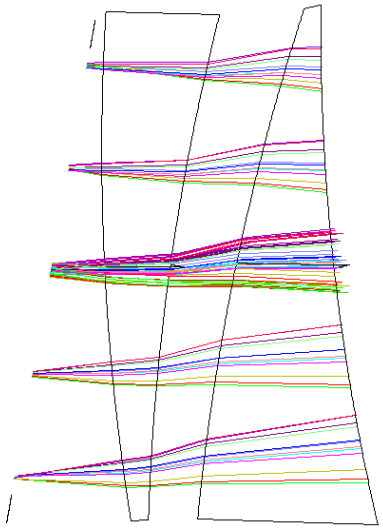


Size of a large mountain bike wheel

Supernova Spectroscopy

- Slitless prism implementation – update since February
  - Additional slot added to element wheel
  - Prism design baselined for PDR
    - Two-element prism with all spherical surfaces meets wavefront specs over full FOV.
  - Expect operations, data reduction to be essentially similar to grism
    - Will need dedicated calibrations, but possibly not new software.
  - Wide range of candidate supernova programs evaluated with prism spectroscopy
    - Most likely scenario is a survey that is primarily imaging to maximize the number of SN light curves, with prism spectroscopy for a subset of the sample to obtain spectral templates for calibrating light curve shapes for sub-populations of SNe.

WFI – slitless prism implementation



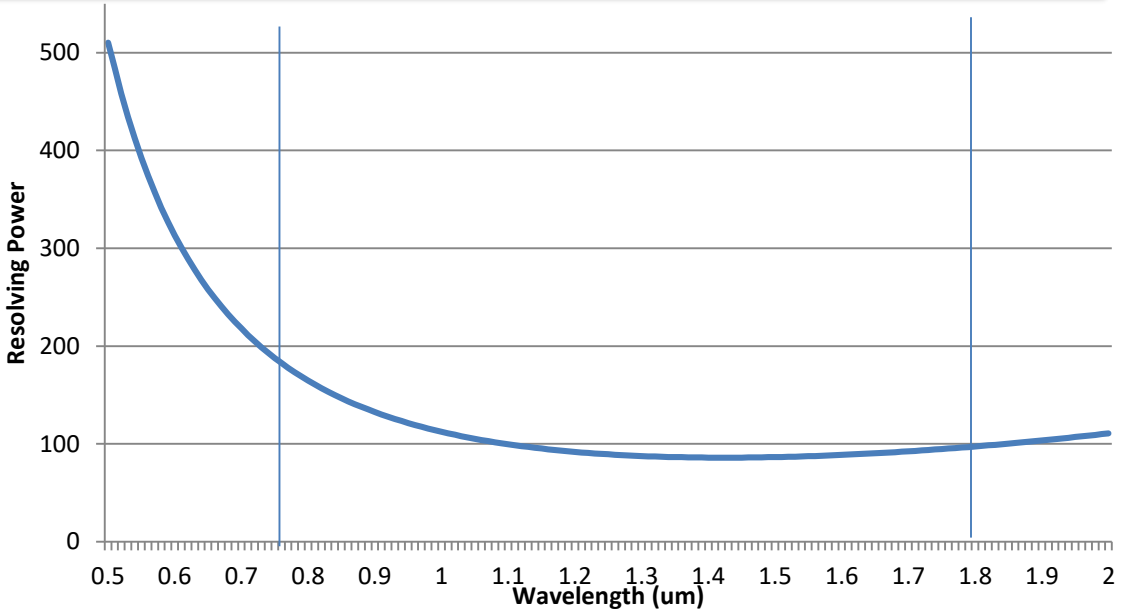
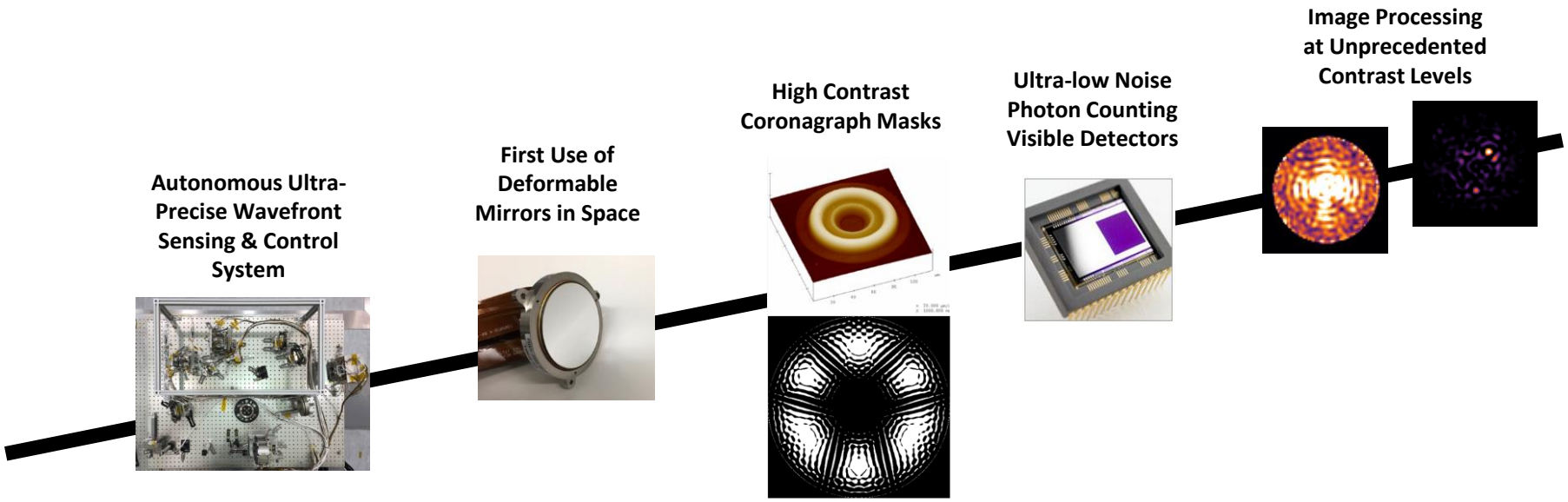


Table shows 2 sample SN programs using prism
Both have 11900 SNIa light curves from a 24.9 deg^2 imaging program

Tier	Imaging time per visit	Prism time (hours)	Max z for SN Ia spectra	# SNIa spectra	Area surveyed in 6 months over 2 yrs, 5 day cadence
Wide tier	8.9	0	n/a	n/a	24.9 deg^2
Deep Tier #1	13.6	7.5	1.3	1528	12.3 deg^2
Deep Tier #2	13.6	7.5	1.7	578	12.3 deg^2

Coronagraph Technology Demonstration Instrument

Technology	• Low-order Wavefront Sensing and Control • Deformable Mirrors • Broad-band Coronagraphic Masks for Very High Contrast • Ultra-low Noise Photon Counting Detectors • High Contrast Imaging on Obscured / Discontinuous Aperture • Slit+prism spectroscopy at Very High contrast



- CGI will premiere in space many key technologies required for the characterization of rocky planets in the Habitable Zone (HZ), significantly reducing the risk and cost of future possible mission concepts such as HabEx and LUVOIR
- CGI is a direct & necessary predecessor to these missions, and is a crucial step in the exploration of Sun-like planetary systems

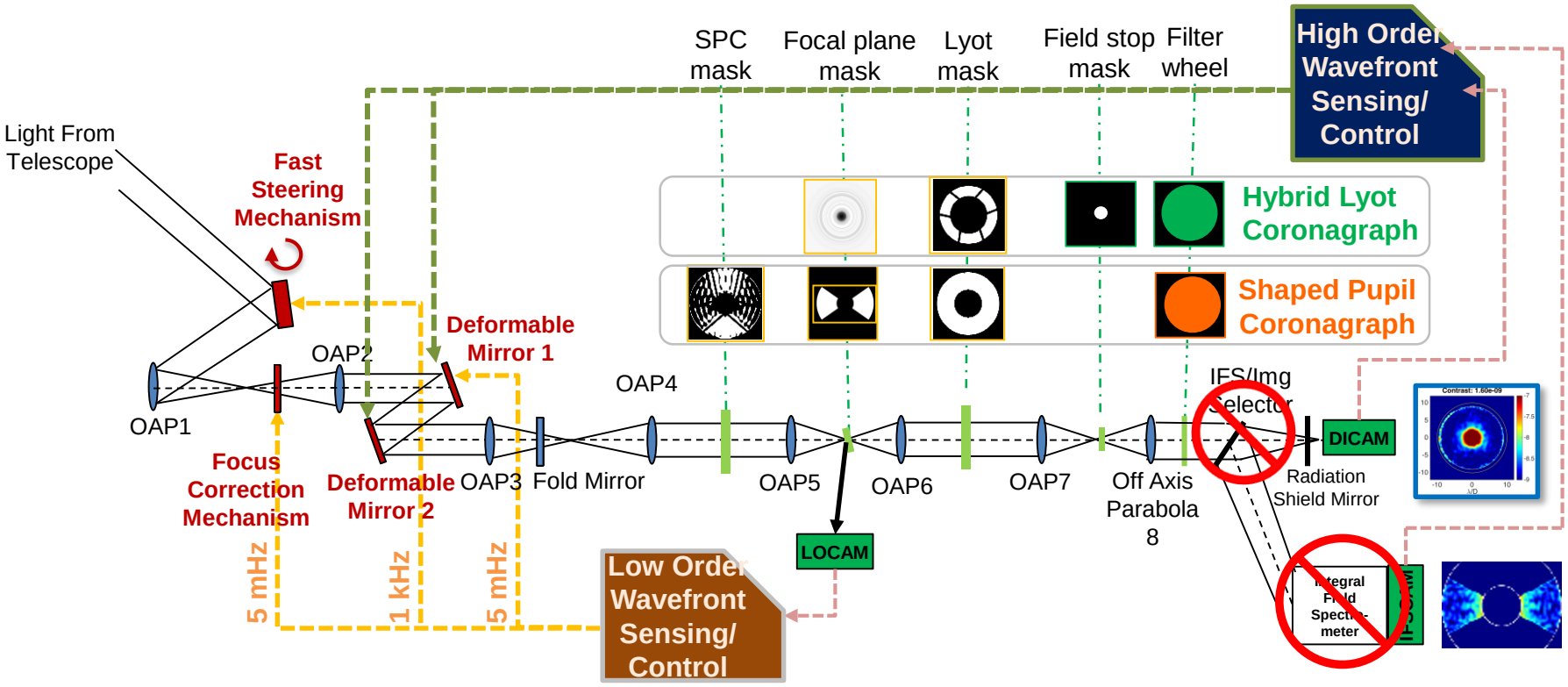
Coronagraph Modes

- As a technology demonstration instrument, the supported modes are limited to those necessary to implement three basic observing scenarios:
  1. Point-source imaging over a narrow field of view
     - Includes polarimetry of a bright source
  2. slit + amici prism spectroscopy over a narrow field of view*
  3. Extended source imaging over a wide field of view
- These three "official" modes will be fully commissioned before launch.
  - the flight hardware will by fully tested with flight software before launch

CGI Filter	λ_{center} (nm)	BW	Channel	Mask Type	Working Angle	Can use w/ linear polarizers	Starlight Suppression Region
1	575	10%	Imager	HLC	3-9 λ/D	Y	360°
3	730	15%	Imager*	SPC bowtie	3-9 λ/D		130°
4	825	10%	Imager	SPC wide FOV	6.5-20 λ/D	Y	360°

*Had been integral field spectrograph channel for demonstrating spectroscopy

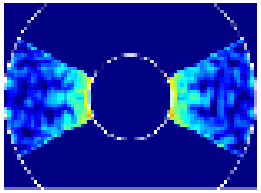
Prior Coronagraph Layout w/IFS



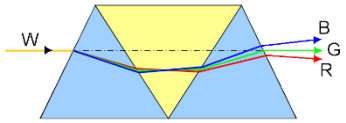
New baseline for spectroscopy

Shaped Pupil Spectroscopy Mode

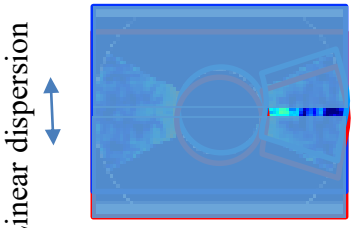
The Amici prisms disperse the 15% bands (Band #2 and Band #3) to produce R≥50 spectra from 600 to 900nm at DICAM



SPC images in 2 15% bands

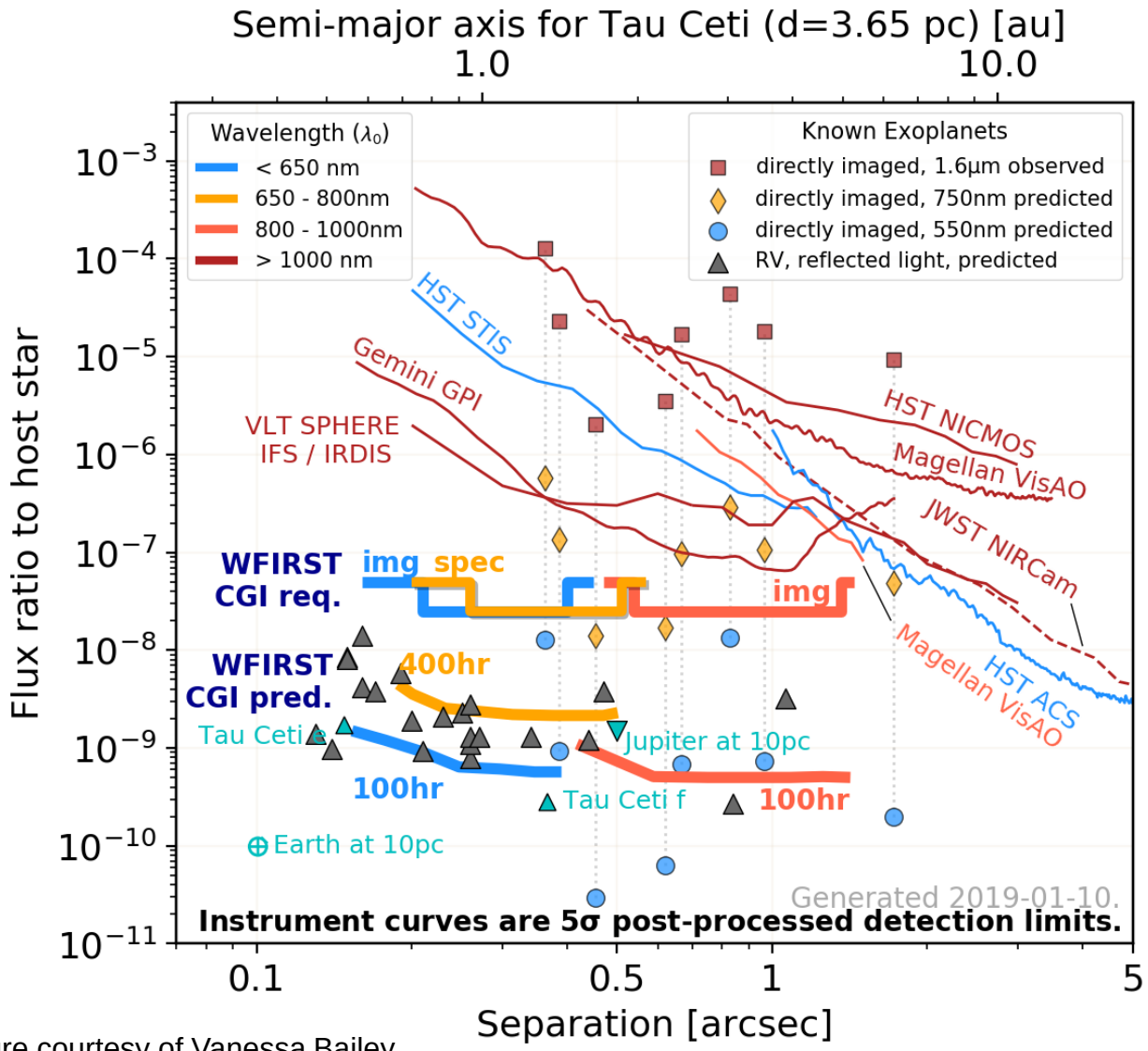


Amici prism



Spectrum to be extracted from dispersed images. Assume we also have the direct image and speckle field.

Coronagraph Predicted Performance



Spectroscopic sensitivity unchanged relative to IFS – possibly slightly better

Figure courtesy of Vanessa Bailey

Science Investigations

- All observing time to be selected competitively
  - Some close to launch, the rest periodically thereafter
- All data will be public immediately
  - Archival research will be funded on a par with GO programs
- Scientific priorities to be updated throughout mission, based on landscape at the time
- Coronagraph available through a Participating Scientist Program
- Present Science Investigation Teams in place through CDR
  - Call for new teams to follow as soon as possible

WFIRST as a Survey Facility

- The power of WFIRST is not *just* that it has a large field of view: it is also very efficient
  - Rapid slew & settle, no Earth occultations, no South Atlantic Anomaly
- Comparisons of total elapsed time for large HST surveys with WFIRST for equivalent area+depth:
  - 3-D HST: 1400 ksec grism spectroscopy over 0.17 sq deg
    - -> WFIRST: 1.9 ksec or 730x faster
  - COSMOS: 3300 ksec imaging over 2 sq deg
    - -> WFIRST: 26 ksec or 125x faster
  - CANDELS *Wide NIR*: 0.22 sq deg in 1790 ksec
    - -> WFIRST: 1.7ksec or 1050x faster
  - PHAT: 2360 ksec multi-band imaging over 0.5 sq deg
    - -> WFIRST: 1.6 ksec or 1475x faster

For details, see Akeson et al 2019 https://arxiv.org/abs/1902.05569

Summary

- FY 2020 budget in House fully funds WFIRST
- FY 2020 budget in Senate would stretch out schedule to launch
  - May have to adjust plans based on final bill from Conference Committee
- Direction from HQ is to proceed with baseline plan while Congress deliberates

- The year ahead:
  - Fabrication/testing of engineering development/test unit hardware ramping up
  - Begin/continue flight hardware fabrication
    - Telescope, NIR detectors, some spacecraft components
  - All reviews, engineering development, procurements are on schedule
  - All technical and programmatic margin/reserves exceed requirements
  - If FY2020 funding is close to House bill, we should remain on track for CDR in Summer of 2021.

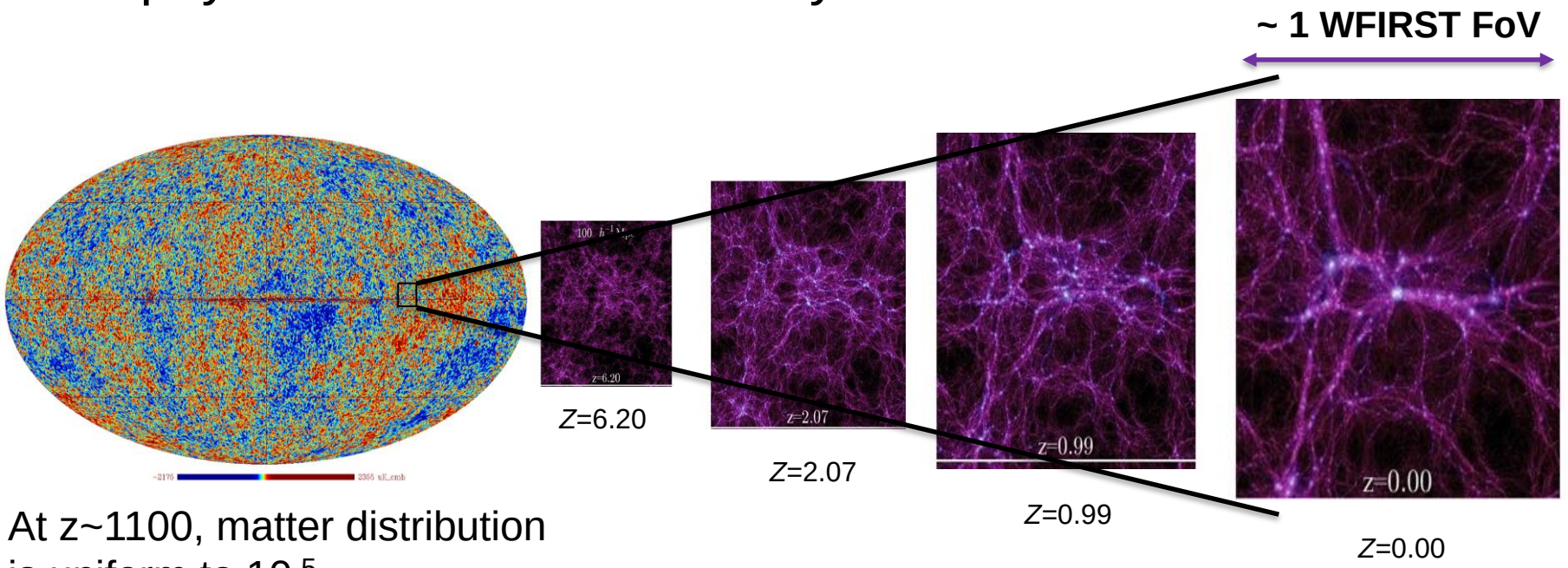
QUESTIONS?

Wide FoV enables study of evolution of the Universe

WFIRST will measure expansion history *and* growth of structure

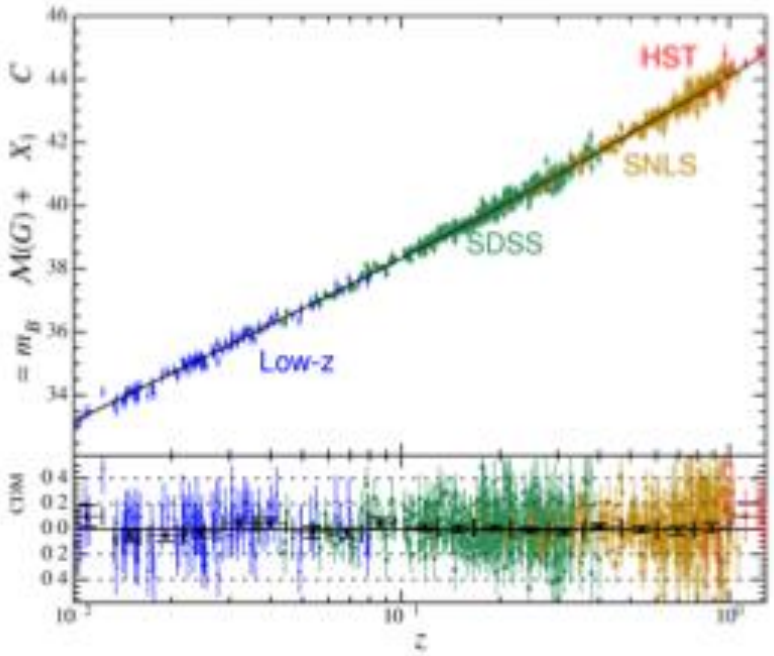
- If results discrepant -> breakdown of general relativity
- If results agree -> learn about nature of dark energy

WFIRST provides multiple probes, enabling cross-checks for astrophysical and instrumental systematics

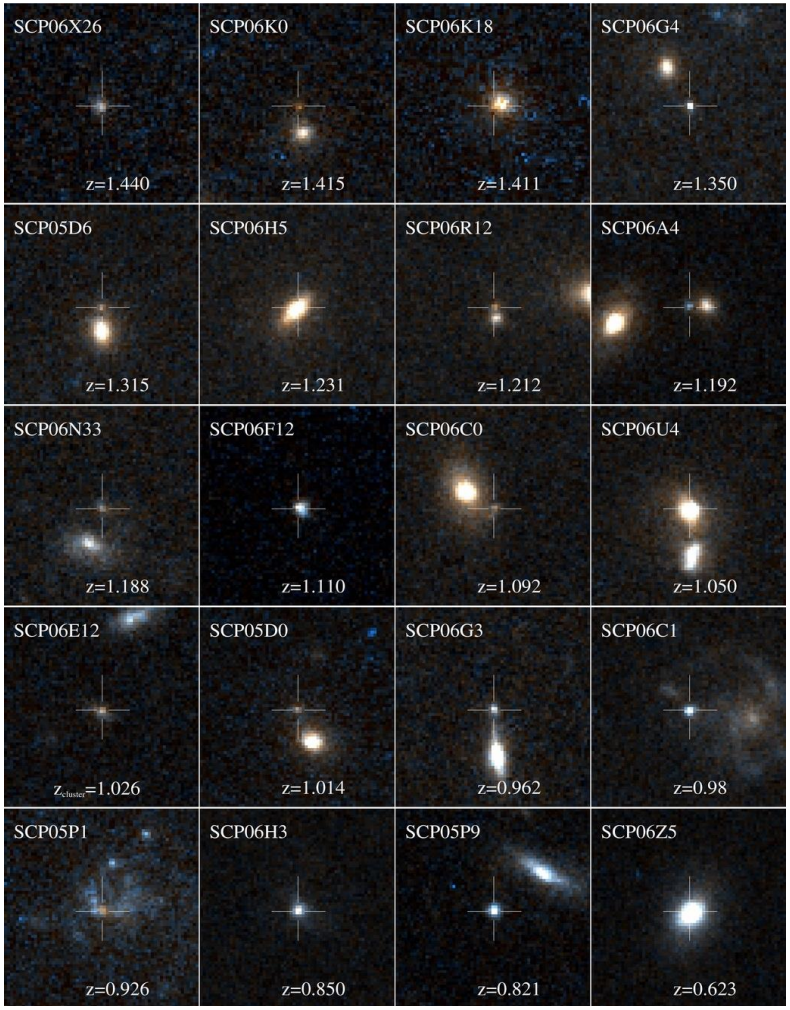


At z~1100, matter distribution is uniform to 10^{-5}

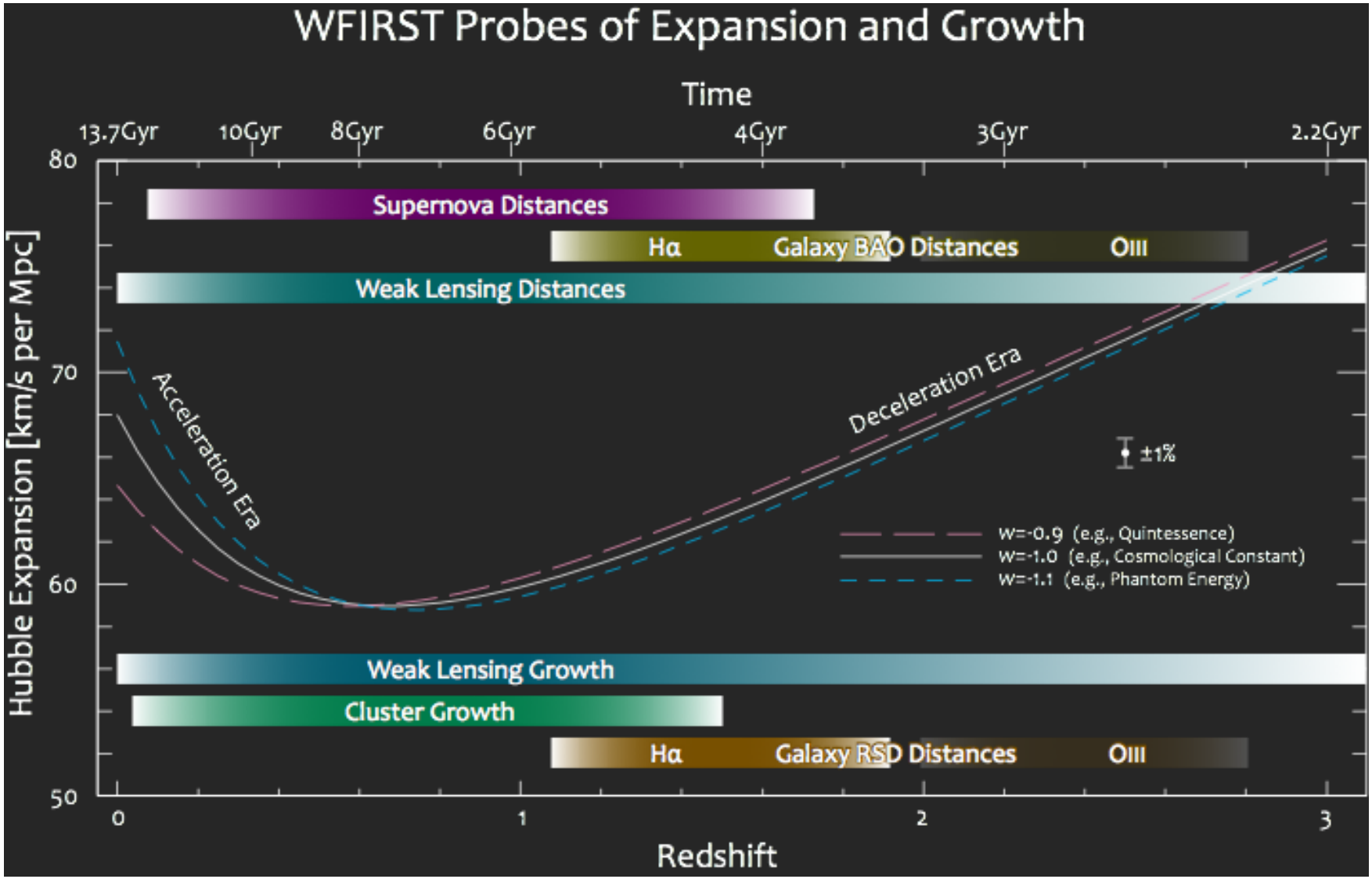
Luminosity distance from SNIa



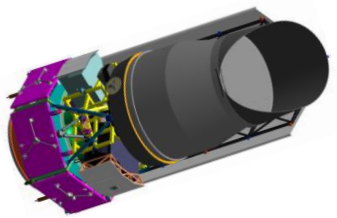
Hubble diagram from Betoule et al 2014, w/best-fit Λ-CDM model



Key next steps are to reduce systematic uncertainties, increase sample at redshift > 1

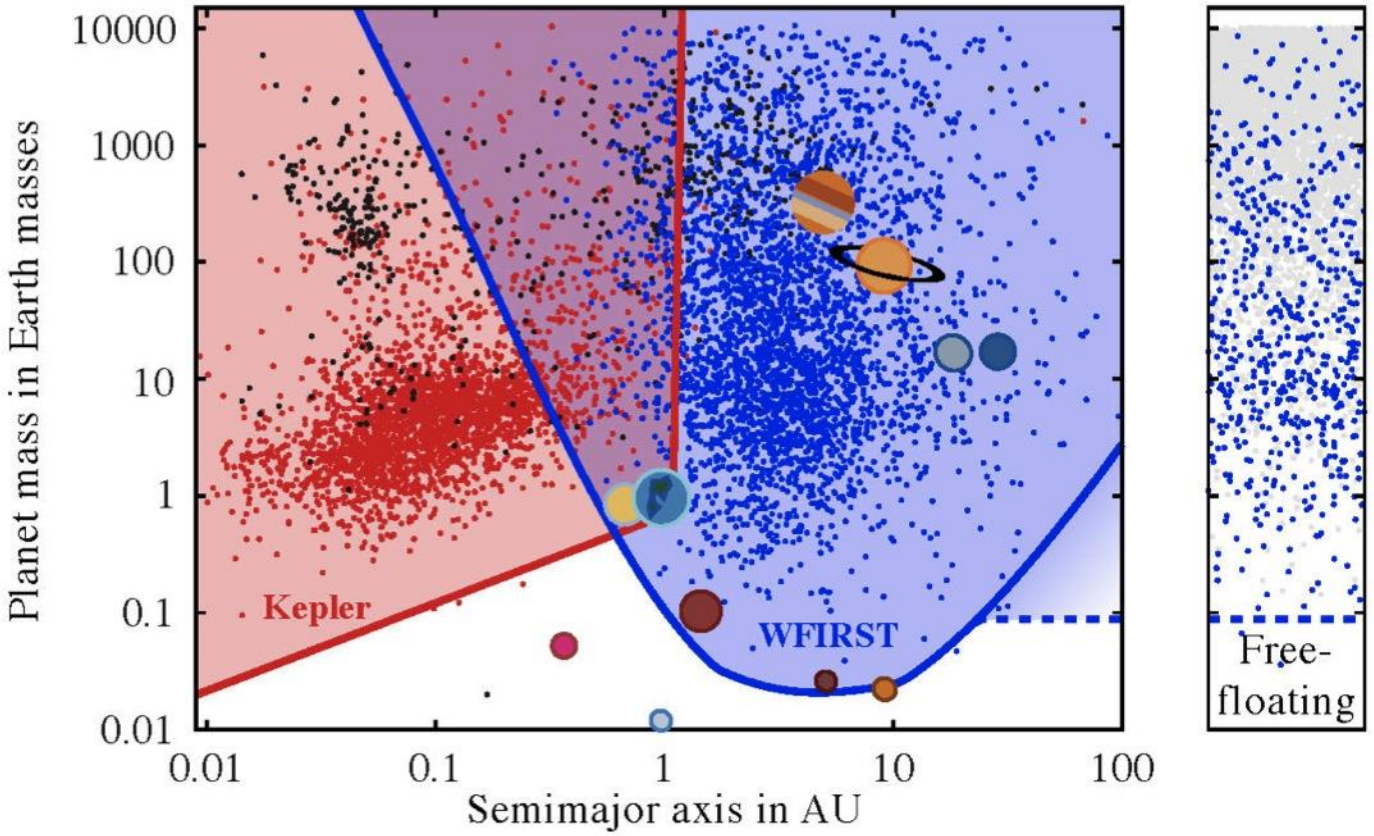

WFIRST Probes of Expansion and Growth
Time
13.7Gyr
10Gyr
8Gyr
6Gyr
4Gyr
3Gyr
2.2Gyr
Supernova Distances
Hα
Galaxy BAO Distances
OIII
Weak Lensing Distances
Acceleration Era
Deceleration Era
±1%
w=-0.9 (e.g., Quintessence)
w=-1.0 (e.g., Cosmological Constant)
w=-1.1 (e.g., Phantom Energy)
Weak Lensing Growth
Cluster Growth
Hα
Galaxy RSD Distances
OIII
Hubble Expansion [km/s per Mpc]
H(z) / (1+z)
80
70
60
50
0
1
2
3
Redshift

Compete the Census of Exoplanets - Microlensing



Kepler

WFIRST



But that is just the beginning…

- Assembly and star-formation histories of galaxies
  - Nearby galaxies & globular clusters out to high redshift
  - Compare high & low density environments, including voids
- Probing the epoch of reionization
- Milky Way kinematics and formation history
- EM counterparts of GW events; multi-messenger astronomy
- Transiting planets in MW disk and bulge
- Astrometric planet detection around nearby stars
- Census of free-floating planets, neutron stars, black holes in MW disk
- Growth & evolution of galaxy clusters (+ X-ray, SZ, LSST, ELTs…)
- Cosmic infrared background
- Discovery of high-z quasars
- Stellar IMF in different environments

Sample from 50+ WFIRST-related white papers submitted to Astro-2020

WFI Filters & dispersers

Band	Element name	Min (µm)	Max (µm)	Center (µm)	Width (µm)	R
R	F062	0.48	0.76	0.620	0.280	2.2
Z	F087	0.76	0.977	0.869	0.217	4
Y	F106	0.927	1.192	1.060	0.265	4
J	F129	1.131	1.454	1.293	0.323	4
H	F158	1.380	1.774	1.577	0.394	4
	F184	1.683	2.000	1.842	0.317	5.81
Wide	F146	0.927	2.000	1.464	1.070	1.37
GRS	G150	1.0	1.93	1.465	0.930	461λ(2pix)
PRS	P127	0.75	1.80	1.275	1.05	80-170 (2pix)

Representative Continuum Sensitivity

Limiting point-source sensitivity (AB mag) in 1 hour of exposure time, Zodiacal light set at twice minimum.

Imaging, 5σ						
R062	Z087	Y106	J129	H158	F184	W149
28.5	28.2	28.1	28.0	28.0	27.5	28.3

Spectroscopy, 10σ per pixel in continuum			
	0.8 μm	1.1 μm	1.5 μm
Grism	N/A	20.78	20.48
Prism	22.87	23.45	23.54

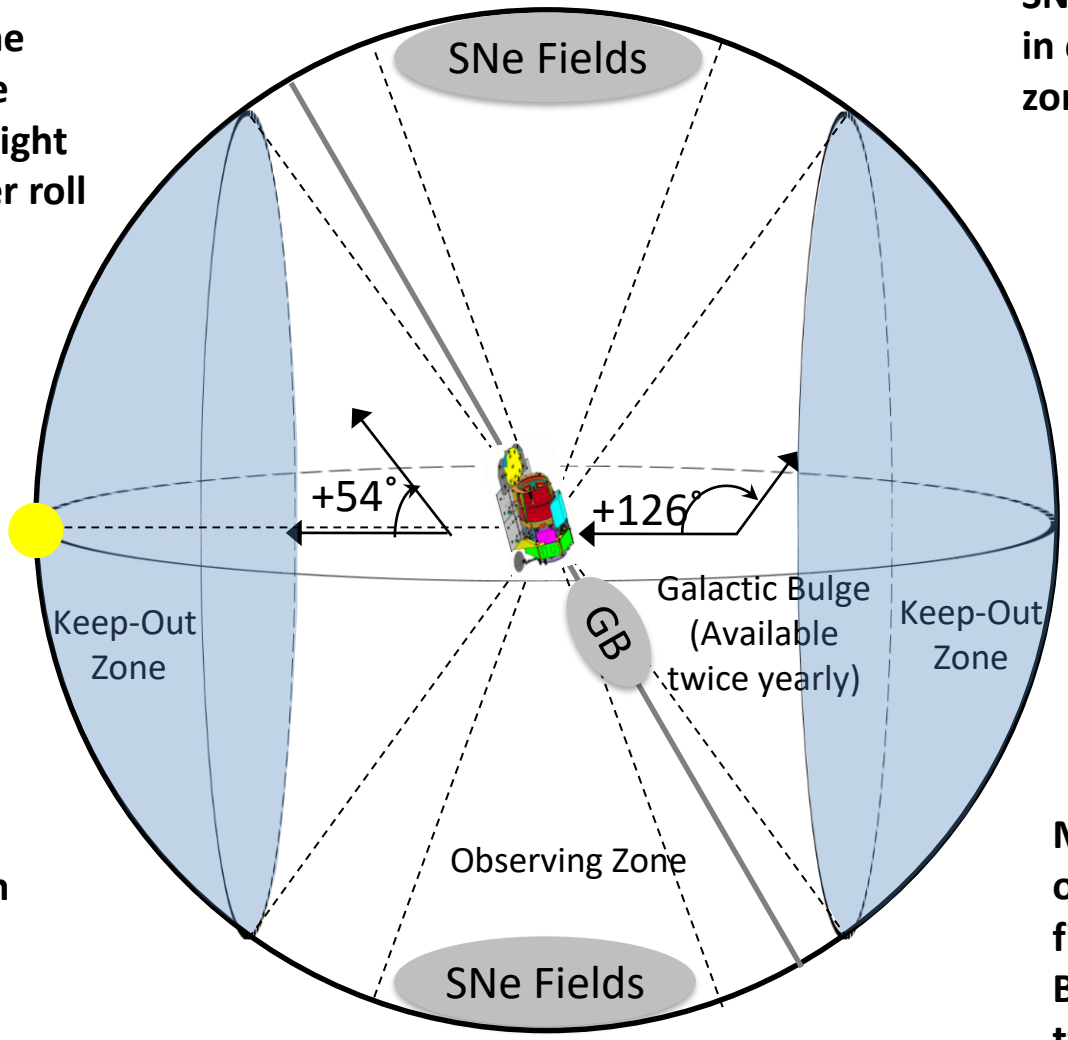
Representative Emission Line Sensitivity (grism)

Emission line flux detected at 6.5σ in one hour, with zodiacal light set at twice minimum.
Units are 10^{-17} ergs/cm^2/sec

Wavelength	Source half-light radius	
µm	0.0”	0.2”
1.05	7.8	17.0
1.15	5.6	12.25
1.25	5.0	10.5
1.35	4.8	9.7
1.45	4.8	9.6
1.55	5.0	9.8
1.65	5.5	10.5
1.75	5.9	11.3
1.85	6.7	12.3

Field of Regard

Observing Zone:
- **54˚-126˚ off Sun Line**
- **360˚ about Sun Line**
- **±15˚ about line of sight (LOS) off max power roll angle**



SNe fixed fields located in continuous viewing zone

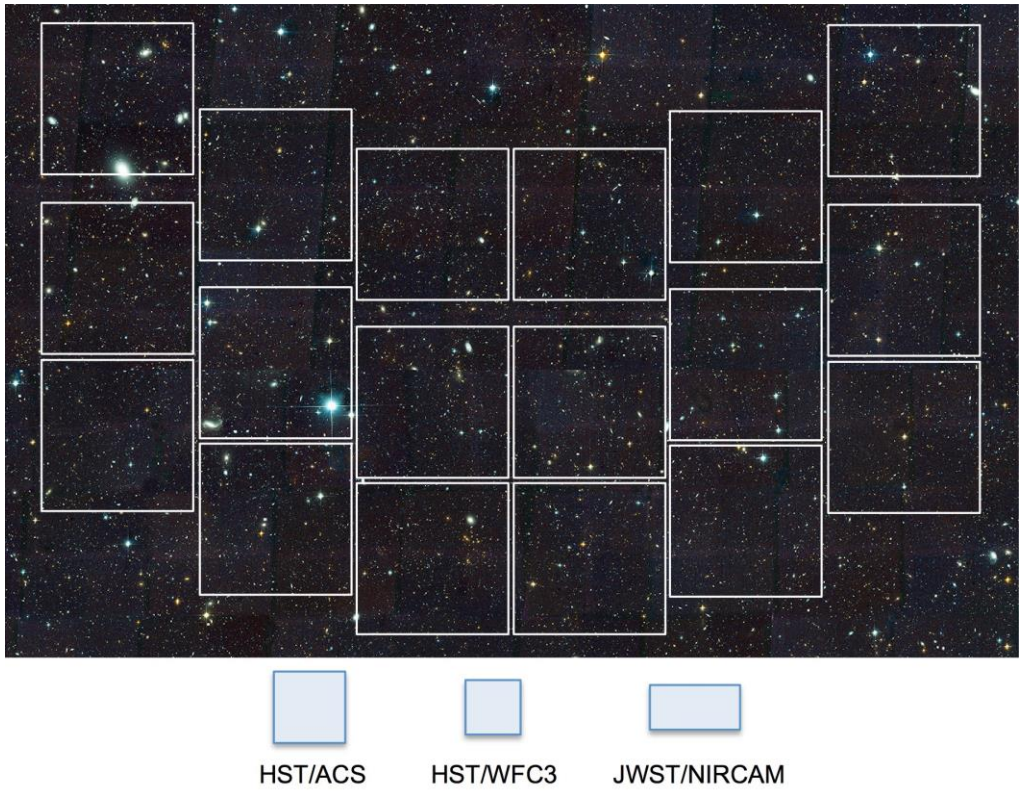
Earth/Moon LOS avoidance angles are a minor sporadic constraint

HLS/GO/Coronagraph observations can be optimized within the full Observing Zone

Microlensing can observe inertially fixed fields in the Galactic Bulge (GB) for 72 days twice a year

Wide-Field Instrument

WFIRST Field of View



Diffraction-limited imaging
0.28 square degree FoV
0.11” pixels
18 4kx4k NIR detectors
R~4 filters spanning 0.48-2.0 μm
Sensitivity: 27.8 H(AB) @5σ in1hr

Slitless grism:
1.0-1.93 μm
R: 435-865

Slitless prism:
0.75-1.8 μm
R: 80-170